Traffic-load Aware Spectrum Allocation in Cloud Assisted Cognitive Radio Networks

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***Abstract*—With diverse technological advancements, the necessity of opportunistic spectrum usage is increasing rapidly to address the rising dearth of available spectrum. Cloud assisted Cognitive Radio Network (CCRN) offers huge computation and storage resources for handling heterogeneous spectrum usage decisions. In this paper, we develop a traffic-load aware channel allocation mechanism for secondary users with respect to their application Quality-of-Service (QoS) requirements. A historical analysis based channel ranking is also formulated recognizing both availability prediction and transmission quality. The simulation results demonstrate the effectiveness of our allocation scheme compared to the state-of-the-art works.**

***Index Terms*—Cloud, Cognitive Radio Network, Spectrum allocation, QoS, Channel Weight, Request Priority**

I. Introduction

The rapid growth of wireless communication technologies has induced an immense amount of mobile data traffic, which will increase seven-fold from 2016 to 2021 [1]. It not only increases the importance of opportunistic spectrum access, but also the usage of unused spectrum resources and has become one of the prerequisites for technological advancements [2].

Cognitive radio is an intelligent wireless communication mechanism with the ability to learn from the environment and dynamically adapt to utilize the available spectrum [3]. In Cognitive Radio Network (CRN) environment, the Secondary Users (SUs) or unlicensed users opportunistically access unused spectrum bands without creating any interference with the transmission of Primary or licensed Users (PUs). However, the CRN architecture is constrained with data processing capabilities, real time data exchange and storage, which frustrate the efficiency of spectrum management and usage.

Introduction of the computational and storage capabilities of Cloud servers with the concepts of CR can mitigate those limitations and enable shared resource provisioning environment [4]. Cloud assisted Cognitive Radio Network (CCRN) is an emerging research interest [5], where the Cloud infrastructure will manage the spectrum usage and allocation on demand using its contemporary and historical knowledge-base.

Many of the state-of-the-art works have addressed the channel allocation frameworks for CRN environment. However, the integration of Cloud with CRN has received less attention in literature. IoSD [6], one of the leading works in this arena, addresses the heterogeneity in sharing bands and proposes an architectural model for CCRN environment. However, they have not provided any specific working model and channel allocation mechanism. In ROAR [5], a real-time geo-location database assisted spectrum allocation and access mechanism is presented. It serves only a single request at a time from the offering resource set, ignoring user's QoS requirement. Another note-worthy work, namely SAC [7], proposes a reward-penalty based spectrum allocation strategy for CCRN. User requests assigned are based on their transmission demand and geo-location information, without considering channel quality and availability information.

In this work, we propose an architectural model for CCRN environment to formulate an context adaptive channel allocation mechanism, namely CAQ. Several components in the Spectrum Cloud Manager (SCM) will manage the operational activities in a synchronized approach. The major contribution of CAQ are summarized as follows:

- A QoS aware traffic load adaptive channel allocation mechanism for Cloud assisted Cognitive radio Network (CCRN) has been proposed.
- Intelligent two dimensional prioritization is performed:
  - Channels are weighted using historical availability prediction and EWMA based utility calculation.
  - User requests are prioritized using their QoS requirements and waiting time, to avoid starvation.
- The performance evaluation shows significant improvements in over-all throughput, average delay.

The paper is organized as follows. Section II attributes the System Model, section III describes the proposed methodologies and the performance analysis is provided in section IV. Finally Section V concludes the paper.

II. System Model and Assumptions

In the proposed environment, we consider a heterogeneous network comprising users with different application requirements. We are assuming that, there are N number of SUs in the environment and K number of licensed channels, as we can see in Fig. 1. Each licensed channels can be opportunistically accessed by the SUs. The arrival of SUs and PUs follows Poisson Distribution. Each SU needs t time to sense a channel and send the information to the SCM. The SCM collaborates the sensing information and schedules the allocation process on each $t \times 2$ interval. With substantial computation resources

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in cloud, the SCM can wrap up the allocation process in fraction of a microsecond.

We assume that, each SU contains two transceivers: one for channel sensing and another for data transmission. The Control Messages are exchanged over Common Control Channel (CCC) [8]. A cooperative three-state sensing model [9] is adopted, as we can see in Eq. 1, here each busy state is categorized into occupied by SU or occupied by PU.

$$X_t = \begin{cases} n_t & H_0, \\ p_t + n_t & H_1, \\ s_t + n_t & H_2. \end{cases} \tag{1}$$

Here, X_t represents signal received by SU; p_t is the signal transmitted by PU, s_t is the signal transmitted by SU, n_t stands for additive white Gaussian noise.

Different types of SU applications with diverse reliability and delay requirements is considered. We have adopted a QoS model for for different network communication types from literature [10], [11], as shown in Table I.

Table I
TRANSMISSION TYPE FOR QOS PROVISIONING

Transmission type (Φ)	Reliability (r) + Delay index (d)
Voice, Telnet	7
E-commerce, E-mail, Emergency health care, Video conferencing	6
Transactions, Serious browsing,	8
Casual browsing	4
File transfers, CCTV, Health care	5

III. PROPOSED METHODOLOGY

A. CAQ Architectural Components

In the section, we unfold each of the components of the proposed CAQ method.

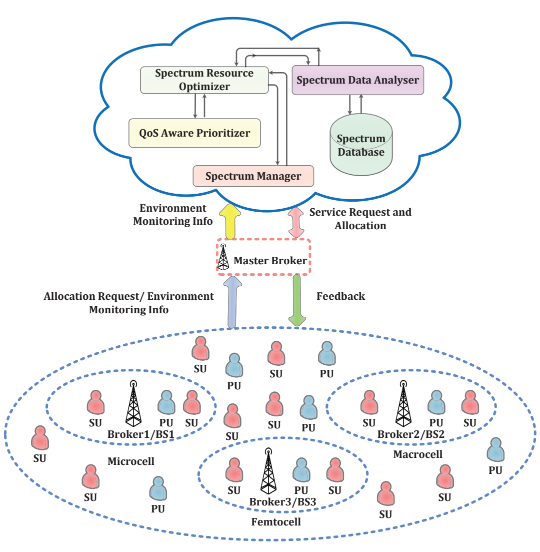

Figure 1. Basic architecture of cloud assisted cognitive radio network

1) Network Environment: The heterogeneous network consists of several small network areas called cells. Each cell is served by at least one base station (BS). There are several spectrum sensors along with SUs residing in each cell. The allocation request and control information of any user from any specific cell or out-cell is sent to the BS or directly to Master Broker (MB).

2) Master Broker: Master Broker is the bridge between heterogeneous network and spectrum cloud. The MB will receive diverse requests from users, send those requests along with environment monitoring information to the cloud. Will forward received feedback to the respective users.

3) Spectrum Cloud Infrastructure: Spectrum cloud infrastructure consists of five interconnected components represented as Fig. 1. *The Spectrum Cloud Manager* (SCM) continuously receives access requests from MB and maintain a request queue. In a certain cycle, SCM sends the batch of requests to *Spectrum Resource Optimizer* (SRO) for further processing. Upon receiving request information from SCM; the Optimizer assigns the workload of data analysis to *Spectrum Data Analyzer* (SDA). SDA analyzes the user information and channel information residing in Spectrum Database. After analyzing the data; it sends the analyzed prediction results back to SRO. SRO also contacts the *QoS Aware Prioritizer* for request prioritization. After receiving feedback from both the components, SDA performs distribution among prioritized SUs and channels. The allocation result is sent back to SCM for redirecting.

B. CAQ Mechanism Operation

Now we will discuss about the computational model of CAQ.

1) Request Prioritization: Each SU sends a request-tuple with the transmission request consisting of all the necessary information as, $< l_i, b_i, r_i, d_i >$. Here, l_i is the packet size of the transmission request, band-width requirement is identified as b_i. The reliability requirement and delay tolerance level is identified as r_i, and d_i respectively.

In each cycle, some of the requests with higher QoS requirements will get served, other will have to wait in the request queue. SCM will maintain the waiting time for each request, which is denoted by ω_i. Now, each request i will be assigned a priority value ρ_i, using Eq. 2, for channel allocation mechanism.

$$\rho_i = (r_i + d_i) \times \omega_i \tag{2}$$

2) Measurement of Channel Weight: We ranked the channels considering channel availability and channel utility to allocate the most QoS sensitive applications with the best resources.

Probability that no PU will come over channel $k \in K$ in the expected transmission period of an SU can be determined using eq. 3. Here, α_k^p is the PU arrival rate over channel k, derivation of this attribute is well explored in literature [12]. $\mathcal{T}_k^t$ is the expected time needed to transfer a packet over that channel.

$$a_k^p = e^{(-\alpha_k^p \times \mathcal{T}_k^t)} \tag{3}$$

Similarly, probability that no SU will not appear over channel $k \in K$ can be determined using the following equation,

$$a_k^s = e^{(-\alpha_k^s \times \mathcal{T}_k^t)} \tag{4}$$

Here, α_k^s is the SU arrival rate over channel k [12]. Now, we have both the probability of channel $k \in K$'s probability of being free from PU and SU, the probability of each channel k being idle during the expected transmission period of SU can be determined as follows,

$$A_k = a_k^p \times a_k^s \tag{5}$$

$\mathcal{T}_k^t$ is the expected time as SU needs to transmit its packet. can be determined using, expected packet length $E[l]$, the maximum achievable data rate of kth channel β_k [12] and average medium access delay in between two consecutive data packet, denoted by $\mathcal{T}_D$. The expected transmission time $\mathcal{T}_k^t$ can be derived as follows,

$$\mathcal{T}_k^t = \frac{E[l]}{\beta_k} + \mathcal{T}_D \tag{6}$$

The basic idea behind channel utility measurement is to find out successful packet transmission ratio for each channel over a certain period [13]. Each SU will send this ratio for each channel, with their sensing information message or channel allocation request. That is, we are adopting a simple ratio of the acknowledgements received with the total packets sent to a channel $k \in K$. Each SU $i \in N$ measures the utility it have received from any channel $k \in K$ as below,

$$U_{i,k} = \frac{P_{i,k}^{Ack}}{P_{i,k}^{Total}} \tag{7}$$

where, $U_{i,k}$ represents the successful packet transmission ratio for i over channel k. $P_{i,k}^{ack}$ is the number of acknowledgements received and $P_{i,k}^{total}$ stands for the total number packets sent through channel k over a certain period by SU i.

After receiving transmission ratio from each SU for each channel, the SCM employ a simple exponential weighted moving average (EWMA) mechanism to calculate an accumulated transmission ratio for each channel. The channel utility $U_{k,t}$ of channel k at time slot t can be derived as follows,

$$U_{k,t} = \frac{\sum_{i=1}^{N} U_{i,k}}{N} \times \sigma + U_{k,t-1} \times (1-\sigma) \tag{8}$$

where, $U_{i,k}$ represents the successful packet transmission ratio over channel k experienced by SU $i \in N$, σ represent the amount of weight given current observation.

Now, each channel will be assigned a value using eq. 9, which will define the weight it carries in the channel allocation process.

$$W_k = A_k \times U_k \tag{9}$$

C. QoS Aware Channel Allocation

In this phase, we have the capability to map a SU with higher priority value to contend over a well ranked channel, so that QoS requirements are fulfilled with channel quality constraints. We employ a mix-integer linear optimization problem, as shown in Eq. 10, to map each relevant requests and channels (i, k), where $i \in R, k \in K$. The remaining requests will be added to the request queue and will be scheduled in next cycle.

$$\text{Maximize } Z = \sum_{i=1}^{R} \sum_{k=1}^{K} \rho_i \times W_k \tag{10}$$

Subject to,

$$A_k \geq A_{th}, \frac{(d_i \times \beta)}{d_{max}} \tag{11}$$

$$U_k \geq U_{th}, \frac{(r_i \times \gamma)}{r_{max}} \tag{12}$$

Here, ρ_i is priority of S_i, W_k stands for the weight of channel k, A_k and U_k present the availability and utility respectively of channel k. r_i and d_i is equivalent to the reliability and delay index of S_i. The SCM upon receiving the final allocation decision from SRO, sends feedback with the respective SUs.

IV. Performance Analysis

In this section, we represent a comparative analysis between our proposed CAQ and SAC [7], implemented in the numerical computing environment of MATLAB.

The simulation is performed for an area of $500 \times 500m^2$, where, 20 PUs and $[10-100]$ SUs are randomly positioned. We are considering 10 licensed channels and 1 CCC, and the data transmission rates varied within $[1-5]$ Mbps. The packets of diverse transmission types generated randomly, each sized 1200 bytes. Each simulation has been conducted for 100 seconds and taken 25 simulation runs each. We consider control propagation delay δ equals 0.83 μs. Reliability and delay index requirements will vary randomly within $[1-4]$. The value of A_{th} and U_{th} is 0.2, β and γ is 0.75.

We will use two metrics for evaluating the performances, system throughput and average delay of SUs. Throughput is a measure of how many units of data bits a system can process in a given amount of time. Average delay consists of waiting time in SCM before allocation along with propagation and transmission delay of the requests.

For the comparative performance evaluation of the studied mechanism we have studied the impact of varying number of SUs on both the metrics. The graphs of Fig. 2 indicate that the performances of the mechanism follow specific trends, as theoretically expected. Initially, very low number of SUs ($<$ 20) in the environment results in reduced traffic injection in the network and thus the network achieves lower throughput. Even in this favorable environment, our allocation mechanism CAQ, outperforms SAC by 15%. With the increasing SUs, the input traffic is increased and we observe performance improvement of CAQ as high as 22.8% over the SAC. Our in-depth look in the simulation trace file reveals that when the number of SU is increasing, SAC fails to maintain its throughput growth, collision, and starvation scales. It down after a certain point. The spectrum allocation considering channel quality of CAQ benefits it even in the most hostile network state, as far as 4%.

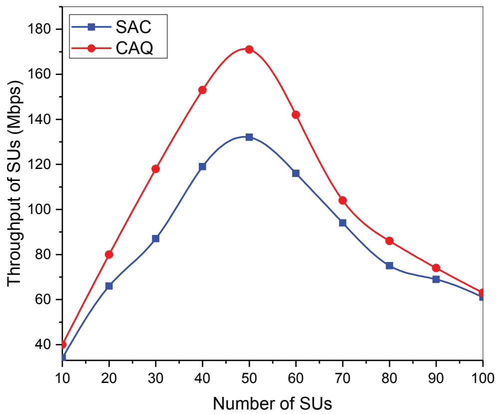

Figure 2. System throughput with increasing number of SUs

For the same arguments as above, our mechanism experiences low average delay with respect to the other implementation, as shown in Fig. 3. SAC mostly considers assigns SUs in a first-come-first-serve manner. The traffic load adaptive QoS aware allocation gives average performance enforcement of 20.68% than SAC, in moderate to extreme network environment. However, in the favorable situation, the mechanisms experiences almost similar behavior, our work still outperforms the other one.

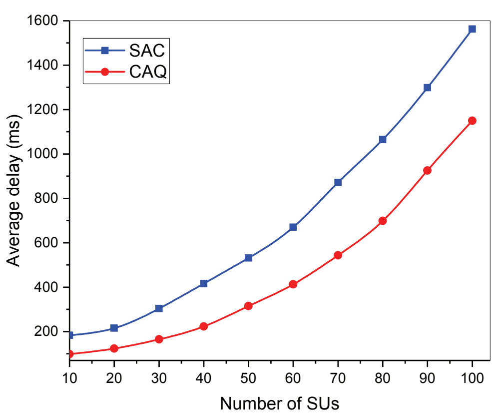

Figure 3. Average delay of requests with increasing number of SUs

V. Conclusion

This work investigated the opportunity of traffic-load aware channel allocation in cloud assisted Cognitive Radio Network. Consideration of both the availability and usage history of channels allowed our proposed CAQ system to adapt with the dynamic environment effectively. The results show significant performance enhancement, compared to an existing work, in terms of throughput and delay. In future, we will study the distributed method of allocation resource in cloud assisted CRN.

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